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A Fuzzy Based Power Flow Control for Hybrid DC-AC Microgrid Using A Bidirectional Converter for Pulsating Loads

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Abstract: A power flow control method for a DC-AC Hybrid microgrid is proposed for pulsating loads. The hybrid microgrid consists of both AC & DC networks connected together by a multidirectional converter. In this microgrid network, it is especially difficult to support the critical load without incessant power supply. In this paper, a fuzzy logic based hybrid microgrid with solar energy, energy storage and pulsating load is proposed. Battery banks inject or absorb energy on DC bus to regulate DC side voltage. The frequency and voltage of AC side are regulated by a bidirectional AC-DC inverter and performance of hybrid DC-AC microgrid system is analyzed in grid tied mode and islanding mode. Results are verified for AC side under pulsating load with high efficiency and reliability using MATLAB/SIMULINK.

Keywords: Fuzzy Logic Controller, Hybrid Micro Grid, Bidirectional Converter, Pulse Load.

I. INTRODUCTION

In recent years the three phase AC power systems existing due to its different operating voltage levels and over long distance. Their growth has also been attributed to the environmental issues caused by conventional fossil fuelled power plants [1]-[3]. Nowadays, more DC loads like LED and Electric vehicles are connected to AC power systems to save energy and to reduce the pollution caused by the fossil fuelled power plants. There is no longer necessary for long distance transmission if the power is supplied by the local renewable power sources. To connect the Conventional AC system to the renewable power sources, AC microgrid have been proposed and DC power from PV panel and Fuel cell are converted into AC in order to connect to an ac grids. Implanted ac/dc and dc/dc converters. In an ac grid, implanted ac/dc and dc/dc converters are required for various home and office facilities to supply different dc voltages. AC/DC/AC converters are commonly used as drives in order to control the speed of ac motors in industrial plants. DC grids are resurging due to the development and deployment of renewable dc power sources and their inherent advantage for dc loads in commercial, industrial and residential applications. The dc microgrid has been proposed to incorporate various distributed generators and ac sources have to be converted into dc before connected to a dc grid and dc/ac inverters are required for conventional ac loads. Multiple reverse conversions required in individual ac or dc grids may add additional loss to the system operation and will make the current home and office appliances more complicated.

Generally a microgrid consists of interconnected distributed energy resources capable of providing sufficient and continuous energy to a significant portion of internal load demand. A microgrid possesses independent controls, and intentional islanding takes place with minimal service interruption (seamless transition from grid-parallel to islanded operation). Microgrid is a small-scale grid that is designed to provide power for local communities. A Microgrid is an aggregation of multiple distributed generators (DGs) such as renewable energy sources, conventional generators, in association with energy storage units which work together as a power supply network. The main components of a microgrid are distributed generation sources such as photovoltaic panels, small wind turbines, fuel cells, diesel and gas micro-turbines etc and distributed energy storage devices such as batteries, super capacitors, flywheels etc and also critical and non-critical loads Energy storage devices are employed to compensate for the power shortage or surplus within the microgrid. Fig.1 represents the Hybrid microgrid configuration where various AC, DC sources and loads are connected to corresponding AC and DC networks. The various characteristics and the component used in the hybrid microgrid system is depend on the application. The characteristics and component of a hybrid microgrids system greatly depend on the application. At the same time, several researchers have already proposed ideals and models of hybrid AC/DC micro grids [4]-[6], but the systems are either working in grid connected mode or islanding mode. Finally fuzzy logic control based hybrid ac/dc microgrid is proposed in this paper to reduce processes of multiple reverse conversions in an individual ac or dc grid.

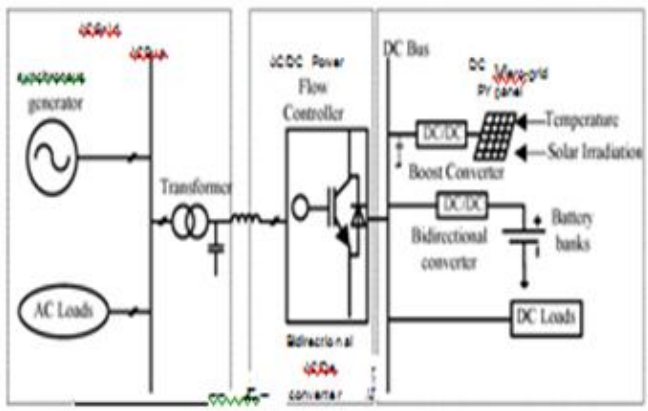


Fig.1. Representation of Hybrid Micro grid.

A. Grid tied mode

If the hybrid system is connected to the utility grid as in Distributed generator application the system design will be simple with reduced no of components. Since the voltage and frequency are set by the utility system. In addition to this, the grid normally provides the reactive power. When the demand is more than the supplied power by the hybrid system, then the shortage is provided by the utility. Similarly, any excess power produced by the hybrid system can be absorbed by the utility system. In such cases, the grid does not act as an infinite bus. However, it is then said to be weak, additional components and control may need to be added. The grid connected mode hybrid system will then come to more closely resemble an isolated one.

B. Islanded mode

Islanded grid connected hybrid system is differs in many ways from central grid connected system. Initially the system must be able to provide all the energy that is required at any time on the grid. They must be able to set the grid frequency and control the voltage. After that the system must be able to provide the reactive power required by the system. Under certain conditions, renewable generators may produce energy in excess of what is needed.

II. PROPOSED SYSTEM MODELLING

A. PV panel Modelling

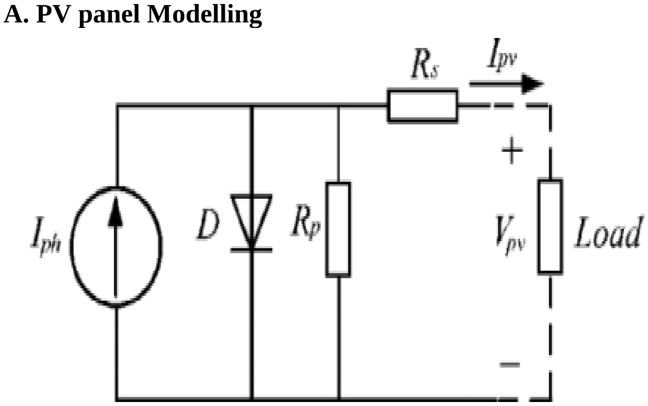


Fig.2. Equivalent circuit of a solar cell.

Fig.2 shows the equivalent circuit of a PV panel with a load. Following equations shows the mathematical model of a PV panel and its output current [7].

$$I_o = n_p I_{ph} - n_p I_{rs}[\exp(k_o v/n_s) - 1]$$

$$Ipv = npIph - npIsat * \left[\exp\left(\left(\frac{q}{Akt}\right)\left(\frac{Vpv}{ns} + IpvRs\right)\right) - 1\right] \quad \textbf{(1)}$$

$$Iph = (Isso + Ki(T - Yr)) * \frac{s}{1000}$$

$$Isat = Irr\left(\frac{T}{Tr}\right)\left(\frac{T}{Tr}\right)^3 \exp\left(\left(\frac{qEgap}{Ka}\right) * \left(\frac{1}{Tr} - \frac{1}{T}\right)\right) \quad \textbf{(2)}$$

B. Simulink model

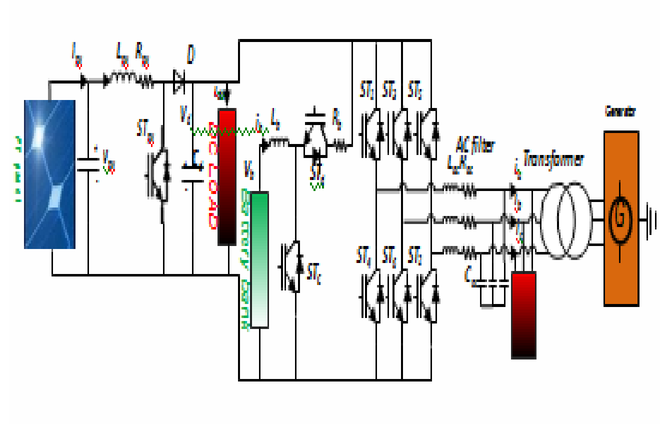


Fig2. Simulink model of proposed topology.

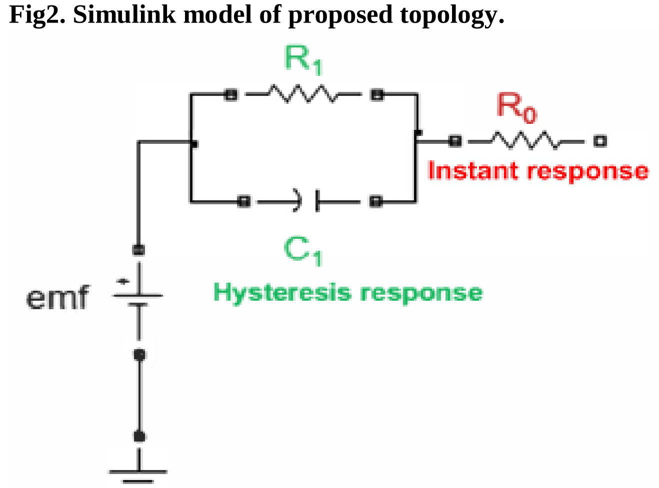


Fig.3. Lithium-ion battery equivalent circuit.

C. Modelling of Lithium-ion battery bank

An accurate battery cell model is needed to regulate the DC bus voltage in islanding mode. The battery terminal voltage and SOC need to be estimated during operation. A high Fidelity electrical model of lithium-ion battery model with Thermal dependence is used [8]. The equivalent circuit of the Battery model is shown in Fig.4 The instantaneous response modelled by a resistor Ro and the hysteresis response is Modelled by a non-linear RC circuit R/ and

C/. Emf represents the internal voltage of the battery. All four parameters are varying with different sacs and temperatures, so four lookup tables are established by using the parameter estimation Too box in Simulink Design Optimization for these four Parameters under different sacs and temperatures. The flow Diagram of the parameter estimation procedure is shown in

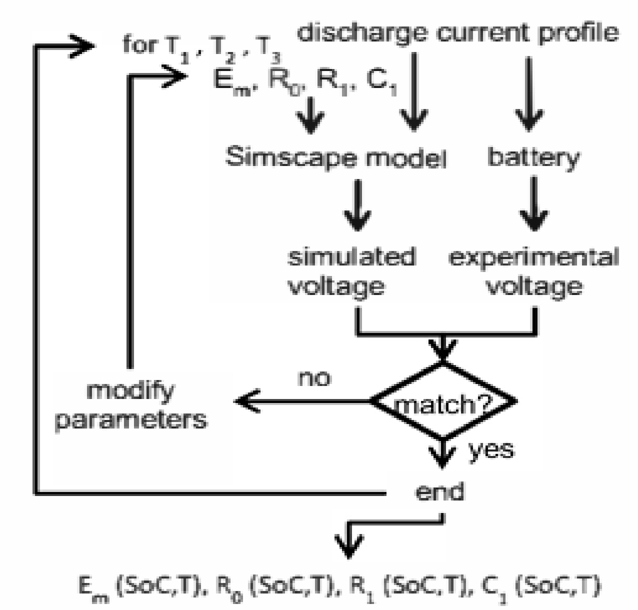


Fig.4. Flow diagram of the parameter estimation procedure.

Fig.4 The SOC of each single battery cell can be calculated by equation (3).

$$SOC = 100(1 + \frac{\int i_b dt}{Q}) \quad (3)$$

III.COORDINATED CONTROL OF THE CONVERTERS

Three types of converters are utilized in this proposed Hybrid micro grid. These converters must be actively controlled in order to supply uninterrupted power with high Efficiency and quality to critical loads on the AC and DC sides during islanding mode. The control method for the converters is discussed in this section.

A. Boost converter control with MPPT

In islanding mode, the boost converter of the PV farm operates in on-MPPT or off-MPPT which is based on the system's power balance and the SOCs of the battery banks. In most situations, this boost converter can operate in the on mode since the variation of the solar irradiance is much slower compared with the power adjustment ability of the AC generator. Therefore, for a given load either on the AC or DC side, the PV should supply as much power as possible to maximize its utilization. However, if the battery banks' SOCs are high (near fully charged) and the PV's maximum output power is larger than the total load in the hybrid micro grid, the PV should be turned to off-MPPT to help the system balance the power flow. In this paper, the perturbation and observe (P&O) method is used to track the maximum power point.

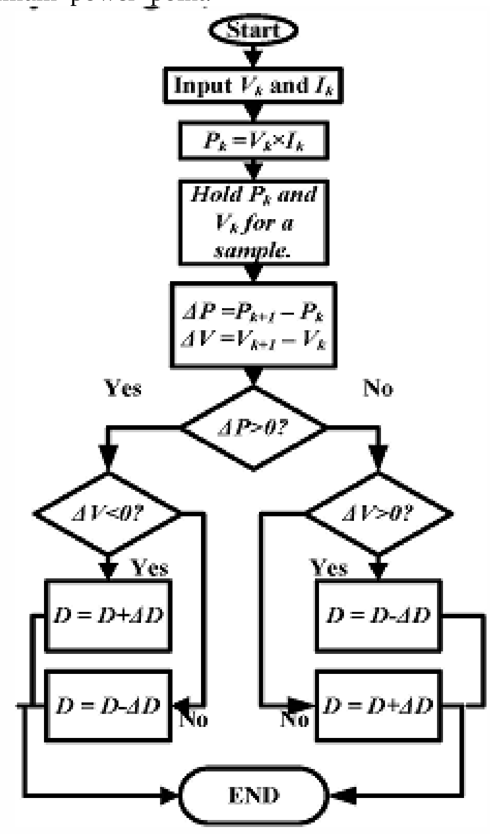


Fig5. Flow chart of P&O MPPT Method.

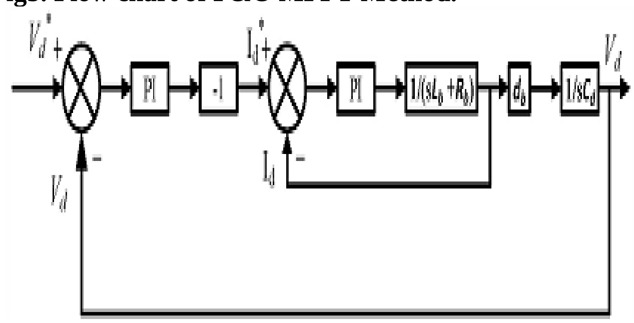


Fig.6 The control block diagram for bi-directional DC-DC converter.

The algorithm utilizes the PV farm output current and voltage to calculate the power. The values of the voltage and power at the k^{th} iteration (P_k) are stored, then the same values are measured and calculated for the $(k+1)^{th}$ iteration (P_{k+1}). The power difference between the two iterations (dP) is calculated. The converter should increase the PV panel output voltage if dP is positive and decrease the output voltage if dP is negative, which finally will adjust the duty cycle. The PV panel reaches the maximum power point when dp is approximately zero. The flow chart of the P&Q MPPT algorithm is given is Fig.5.

B. Bi-directional DC-DC converter control

The bi-directional converters of the batteries play an important role in islanding mode to regulate the DC bus Voltage. A two closed-loops controller is used to regulate the DC bus voltage. The control scheme for the bi-directional DC DC converter is shown in Fig.6 The outer voltage controlled is used to generate a reference charging current for the Inner current controlled loop. The error between the measured DC bus voltage and the system reference DC bus voltage is set as the input of the PI controller, and the output is the reference Current. The inner current control loop will compare the Reference current signal with the measured current flow through the converter and finally generate a PWM signal to drive the IGBT STd or STc to regulate the current flow in the Converter. For example, when the DC bus voltage is higher Than the reference voltage, the outer voltage controller will Generate a negative current reference signal, and the inner current control loop will adjust the duty cycle to force the current flow from the DC bus to the battery, which results in Charging of the battery. The energy transfers from DC bus to the battery and the DC bus voltage will decrease to the normal Value. If the DC bus voltage is lower than the normal value, the Outer voltage control loop will generated a positive current Reference signal, which will regulate the current flow from the Battery to the DC bus and because of the extra energy injected from the batteries, the DC bus voltage will increase to the Normal value.

C. Bi-directional AC-DC inverter control

The frequency and voltage amplitude of the three phase AC side is not fixed during islanding operation so a device is Needed to regulate these variables. A bi-directional AC-DC

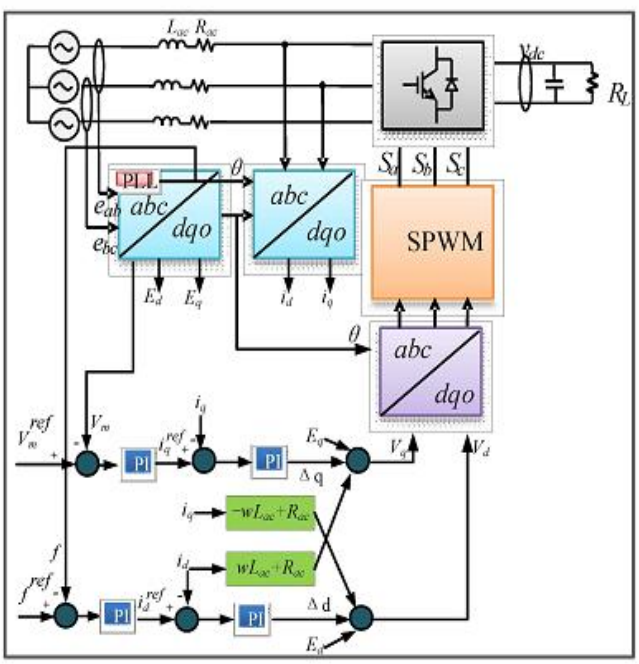


Fig.7 The control block diagram for bi-directional AC-DC converter.

inverter is used with the active and reactive power decoupling technique to keep the AC side stable. The Control scheme for the bi-directional AC-DC inverter is shown in Fig.7. in d-q cord mates, Id IS controlled to regulate the active power flow Through the inverter to regulate the AC side frequency, and Iq is Controlled to regulate the reactive power flow through the Inverter to regulate the AC side voltage amplitude. Multi-loop control is applied for both frequency and Voltage regulation. For frequency control, the error between measured frequency and reference frequency is sent to a PI Controller which generates the id reference. To control the Voltage amplitude, the error between the measured voltages amplitude and the reference voltage amplitude is sent to a PI Controller to generate iq reference. Equations (4) and (5) show The AC side voltage equations of the bi-directional AC-DC Inverter in ABC and d-q coordinate respectively. Where (Va, Vb, Vc) are AC side voltages of the inverter, and (Ea, Eb, Ee) are the voltages of the AC bus. (Lla, LIb, LIe) are the adjusting signals After the PI controller in the current control loop.

$$L_{ac}\frac{d}{dt}\begin{bmatrix}i_a\\i_b\\i_c\end{bmatrix}+R_{ac}\begin{bmatrix}i_a\\i_b\\i_c\end{bmatrix}=\begin{bmatrix}V_a\\V_b\\V_c\end{bmatrix}-\begin{bmatrix}E_a\\E_b\\E_c\end{bmatrix}+\begin{bmatrix}\Delta_a\\\Delta_b\\\Delta_c\end{bmatrix} \tag{4}$$

$$L_{ac}\frac{d}{dt}\begin{bmatrix}i_d\\i_q\end{bmatrix}=\begin{bmatrix}-R_{ac}&\omega L_{ac}\\-\omega L_{ac}&-R_{ac}\end{bmatrix}\begin{bmatrix}i_d\\i_q\end{bmatrix}+\begin{bmatrix}V_d\\V_q\end{bmatrix}-\begin{bmatrix}E_d\\E_q\end{bmatrix}+\begin{bmatrix}\Delta_d\\\Delta_q\end{bmatrix} \tag{5}$$

When the pulse load is connected or disconnected to the AC side, the frequency or the voltage amplitude will be altered. After detecting the variance from the phase lock loop (PLL) or voltage transducer, Id and Iq reference signals will be adjusted to regulate power flow through the bi-directional AC-DC Inverter. Because of the power flow variances, the DC bus Voltage will also be influenced. The DC bus voltage transistor will sense the voltage variance in the DC bus, and the bidirectional DC-DC converter will regulate the current flow Between the battery and the DC bus. In the end, the energy is transferred between the battery and the AC side to balance the Power flow in the system.

IV.FUZZY LOGIC CONTROLLER

Fuzzy logic theory is considered as a mathematical approach combining multi-valued logic, probability theory, and artificial intelligence to replicate the human approach in reaching the solution of a specific problem by using approximate reasoning to relate different data sets and to make decisions. The performance of Fuzzy Logic Controllers is well documented in the field of control theory since it provides robustness to dynamic system parameter variations as well as improved transient and steady state performances. Fuzzy logic controller is preferred over the conventional PI and PID controller because of its robustness to system parameter variations during operation and its simplicity of implementation . The proposed FLC scheme exploits the simplicity of the Mamdani type fuzzy systems that are used in the design of the controller and adaptation mechanism.

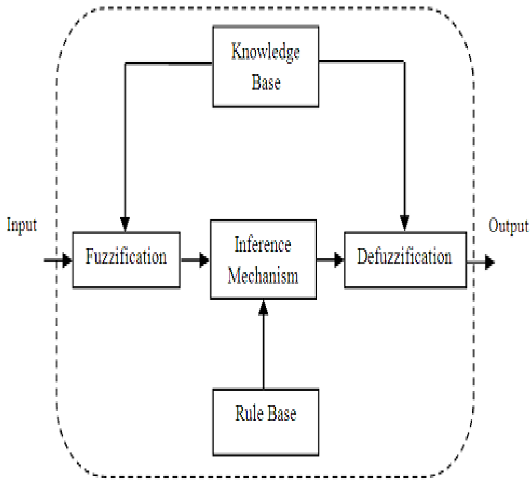


Fig.8. Schematic representation of Fuzzy Logic Controller.

The fuzzy logic based control scheme (Fig.8) can be divided into four main functional blocks namely Knowledge base, Fuzzification, Inference mechanism and Defuzzification. The knowledge base is composed of data base and rule base. Data base consists of input and output membership functions and provides information for appropriate fuzzification and defuzzification operations. The rule-base consists of a set of linguistic rules relating the fuzzified input variables to the desired control actions. Fuzzification converts a crisp input signals, error (e), and change in error (ce) into fuzzified signals that can be identified by level of memberships in the fuzzy sets. The inference mechanism uses the collection of linguistic rules to convert the input conditions to fuzzified output. Finally, the defuzzification converts the fuzzified outputs to crisp control signals using the output membership function, which in the system acts as the changes in the control input (u). The typical input membership functions for error and change in error are shown in Fig 9a and Fig 9b respectively, whereas the output membership function for change in control input is shown in Fig 9c. The output generated by fuzzy logic controller must be crisp which is used to control the PWM generation unit and thus accomplished by the defuzzification block. Many defuzzification strategies are available, such as, the weighted average criterion, the mean-max membership, and center-of-area (centroid) method. The defuzzification technique used here is based upon centroid method.

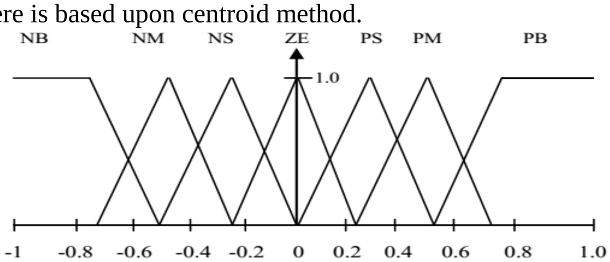


Fig.9a. Membership Function for Input Variable Error, 'e'.

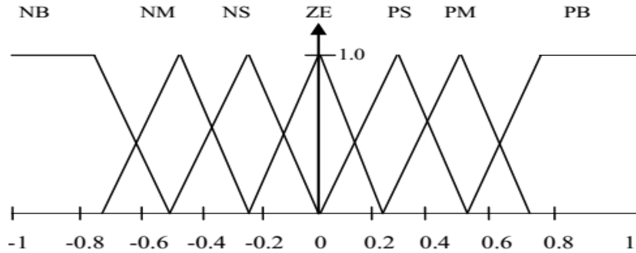


Fig.9b. Membership Function for Input Variable Change in Error, 'ce'.

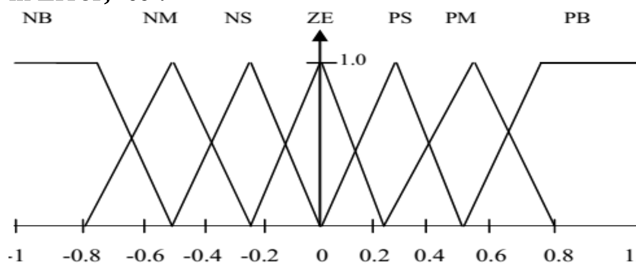


Fig.9c.Membership Function for Output Variable Change in Control Signal, 'u'.

The set of fuzzy control linguistic rules is given in Table 1. The inference mechanism of fuzzy logic controller utilizes these rules to generate the required output.

Table 1. Rule Base for Fuzzy Logic Controller

'ce' \ 'e'	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

V.MATLAB/SIMULINK RESUTS

CaseI: The proposed micro grid with pulse load variation without DC support.

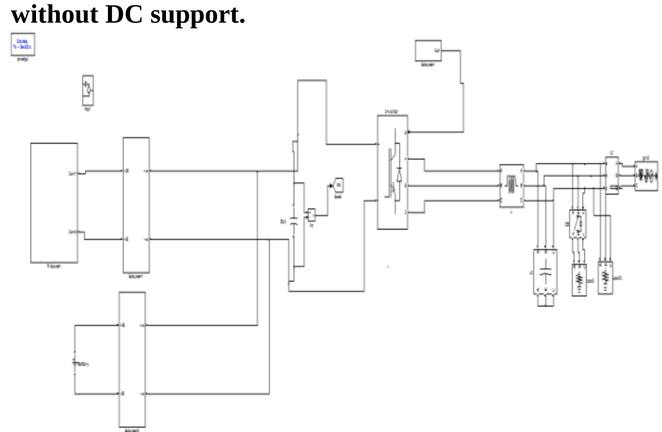
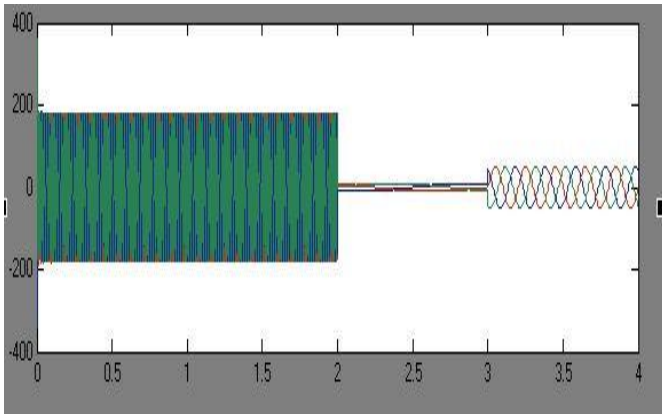
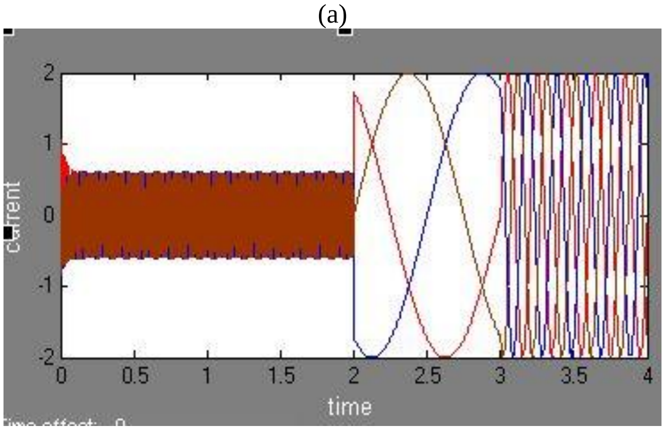


Fig.10.Matlab Simulink model of the proposed micro grid

When the 10 kW resistive pulse load was connected to the AC bus, the total load in the AC side was 14 kW which exceeded the generator's output limitation by 0.2 kW. Fig.11(a),(b) shows the AC side voltage generator's output without DC side aid by the AC-DC inverter. At t = 2.2s, the system collapsed, and both the frequency and voltage dropped considerably. The system couldn't recover even after the pulse load was disconnected after t=3s.



(a)



(b)

Fig11(a)&(b). AC side voltage and current under the influence of pulse load without DC support.

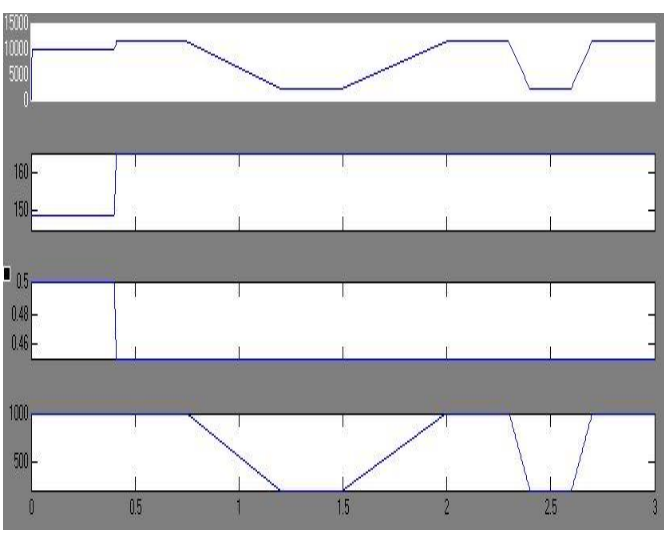


Fig.12. PV farm output power control with MPPT.

The MPPT of the boost converter is enabled at O.4s. The output power, the terminal voltage of the PV panel, the duty cycle of the boost converter and the solar irradiance are shown in Fig.12 For general study, two kinds of solar irradiance variances with different charging rates are used in this study. Before O.4s, the duty cycle is set at 0.5, the terminal voltage of the PV panel is 149V and the output power from the PV panel IS only 9.56 kW. After the MPPT is enabled, the duty cycle is decreased to 0.45. The terminal voltage is increased to 165V. In this way, the PV panel reaches the maximum power output of 10.07 kW. The simulation result is as shown.

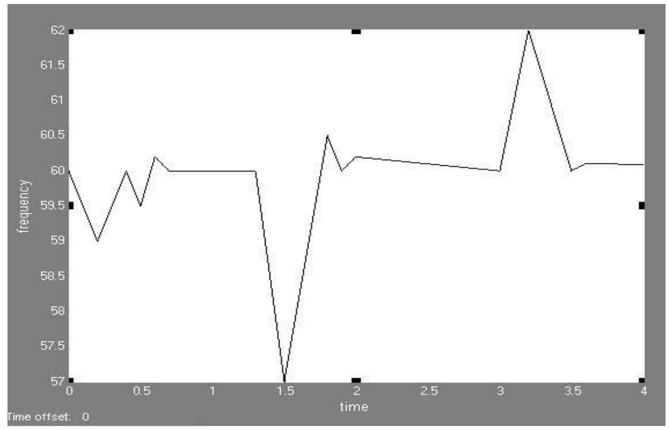
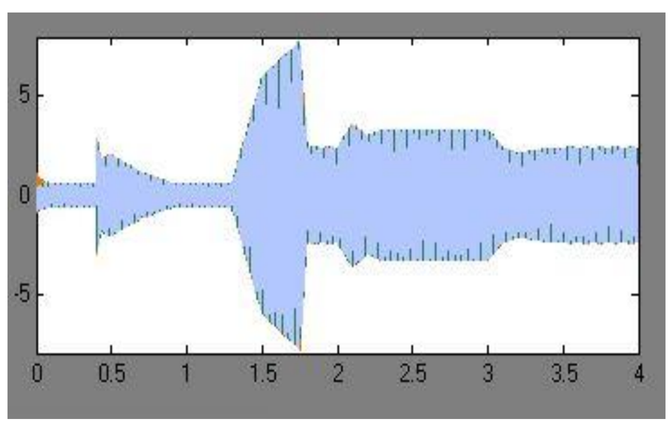


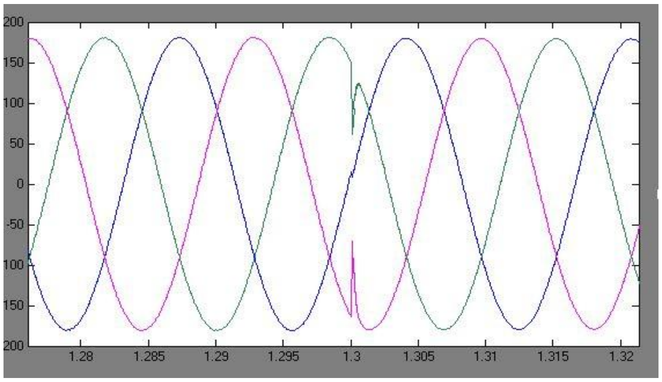
Fig.13. Ac Side frequency response.

CaseII:The proposed micro grid with pulse load variation with DC support

The batteries are able to support the AC side by injecting or absorbing power to the AC bus through the bidirectional inverter that links the AC and DC side. The frequency and voltage amplitude on the AC side also remain stable due to the separate control of the active and reactive power flow control. Fig. 14. (a) and (b). show the AC bus current and voltage. When the pulse load is connected to the AC side, the current flow through the AC bus increased immediately, and after the pulse load disconnected from the AC side, the current slightly decreased to keep the system in balanced. The AC bus voltage transient response during the pulse load variation is shown in Fig. 14 (b). The AC voltage amplitude returned to its normal value in less than three cycles.



(a)



(b)

Fig.14: (a) &(b). Micro grid AC side current and voltage response with DC support.

Case III: The proposed micro grid with fuzzy controller with pulse load variation with DC support

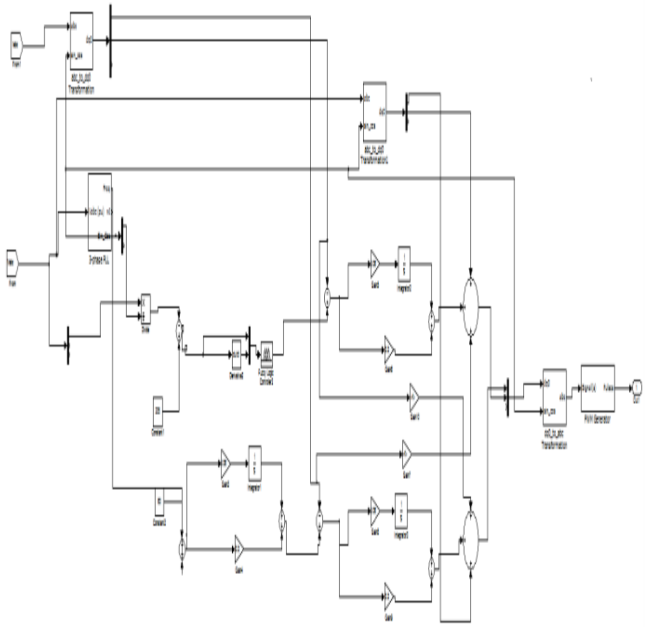
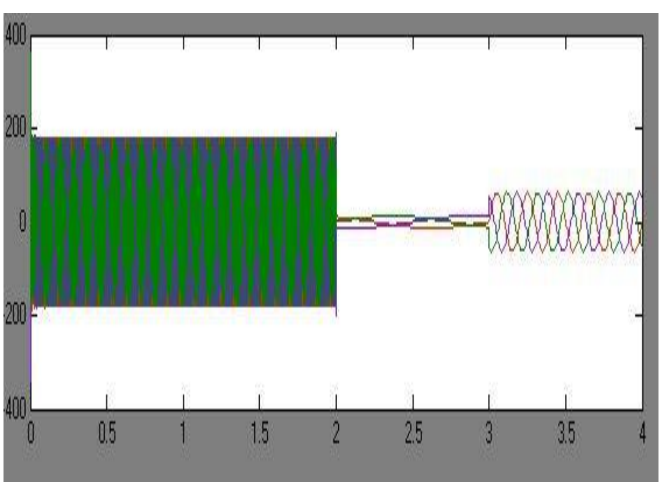
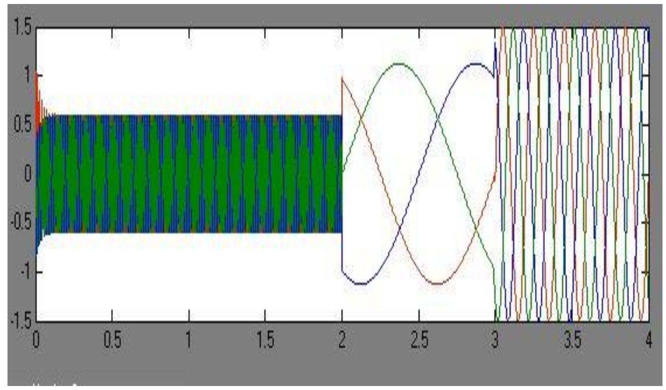


Fig.15. Fuzzy controller for proposed Micro grid.



(a)



(b)

Fig.16. a) & (b) Ac Bus voltage & Current with Pulse load influence with Fuzzy controller.

VI.CONCLUSION

In this paper, a fuzzy logic control based power flow control method of multi power electronic devices is proposed for a hybrid DC-AC micro grid operated in islanding mode. The micro grid has a PV farm and synchronous generator supply energy to its DC and AC side. Battery banks are connected to the DC bus through bi-directional DC-DC converter. The AC side voltage amplitude and frequency are regulated by the bi-directional AC-DC inverter. The system topologies together with the control algorithm are tested with the influence of pulse load. The simulation results show that the proposed fuzzy logic control based micro grid with the control algorithm can greatly enhance the overall system efficiency, stability, and robustness.

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